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AA509 AA529 AA53Y AA537 AA539 AA54X AA579
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AA599 AA60Y AA607 AA609 AA61Y AA615 AA617
AA619 AA62X AA621 AA67X AA671 AA673 AA675
AA677 AA679 AA68X AA681 AA683 AA685 AA687
AA689 AA69X AA693 AA694 AA695 AA696 AA697
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(58) Field of search

UK CL (Edition K) C7A

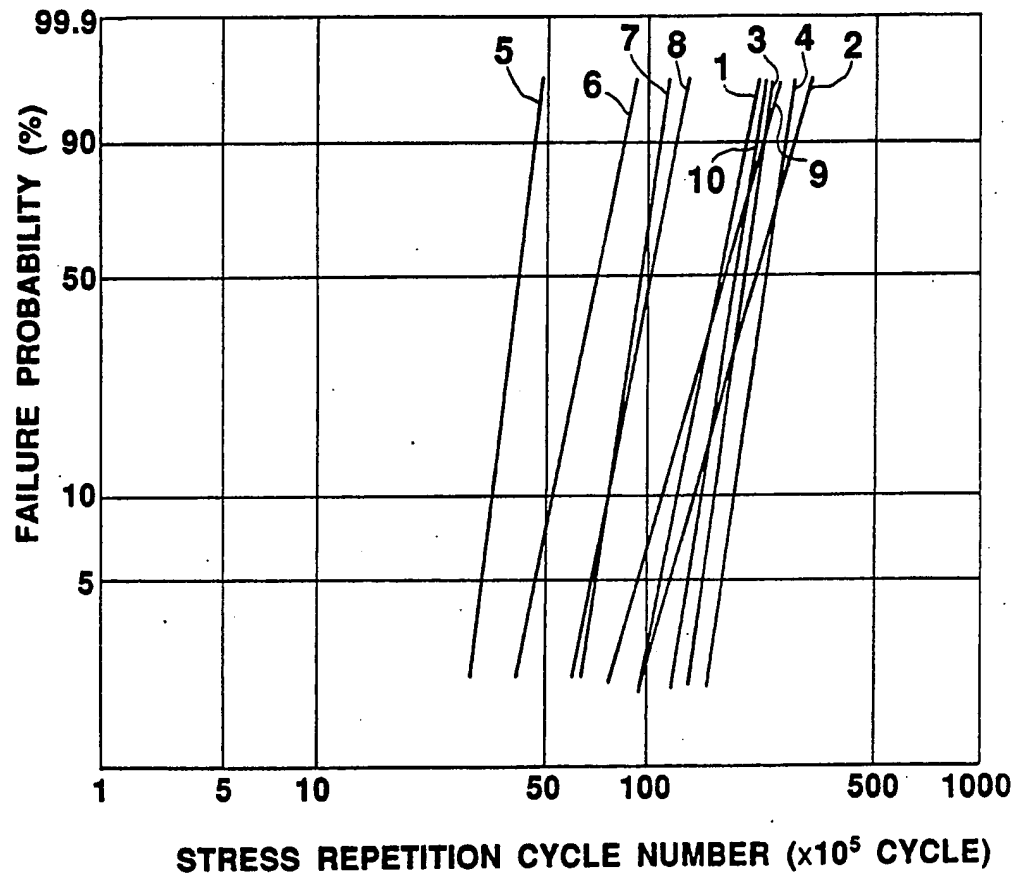
(54) **Bearing steel**

(57) A rolling contact parts steel has C: 0.2-0.6 wt%; Si: 0.3-2.0 wt%; Cr: 0.5-2.5 wt%; Mn: 1.7 wt% or less; O: 12ppm or less; and the balance of Fe and an inevitable impurity. The steel can produce a fine carbide without the need for a separate heat treatment. The dimensional stability at high temperature of the steel is superior. A rolling bearing has at least one of the races and rolling element made of the steel, the steel being carburized or carbonitrided, then quenched and then tempered. The one of the races and rolling element will not soften at a high temperature.

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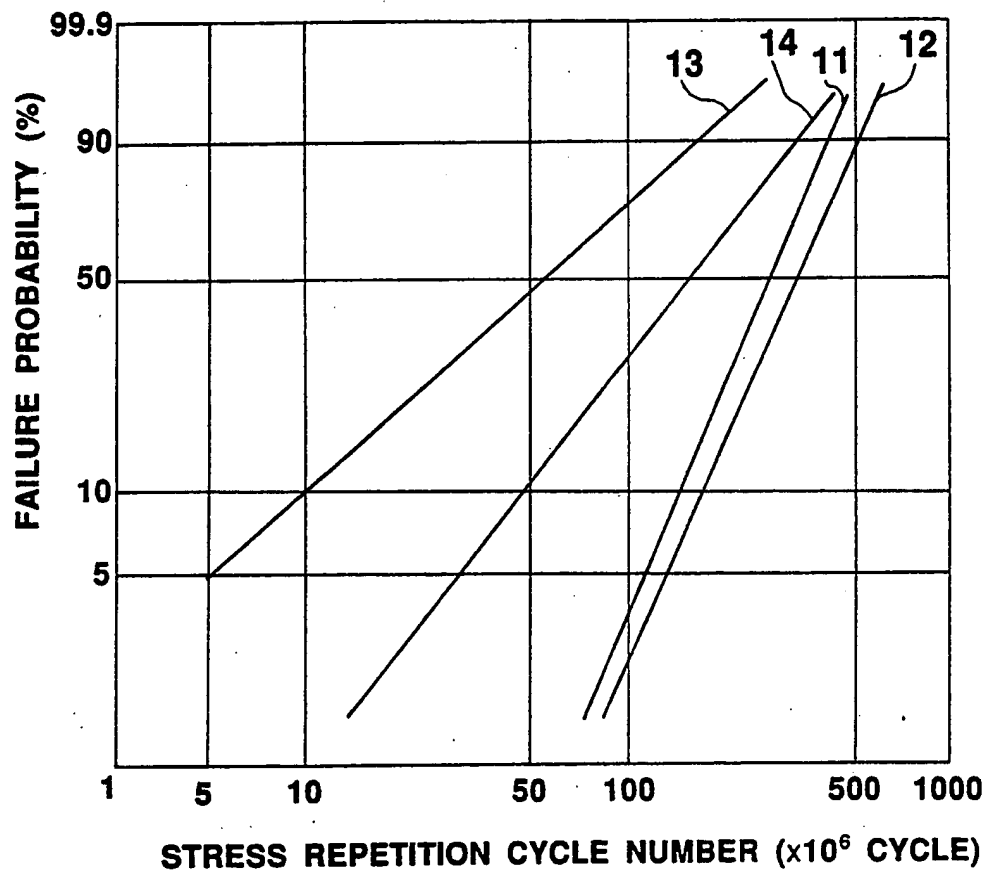
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FIG.1



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FIG.2



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FIG. 3

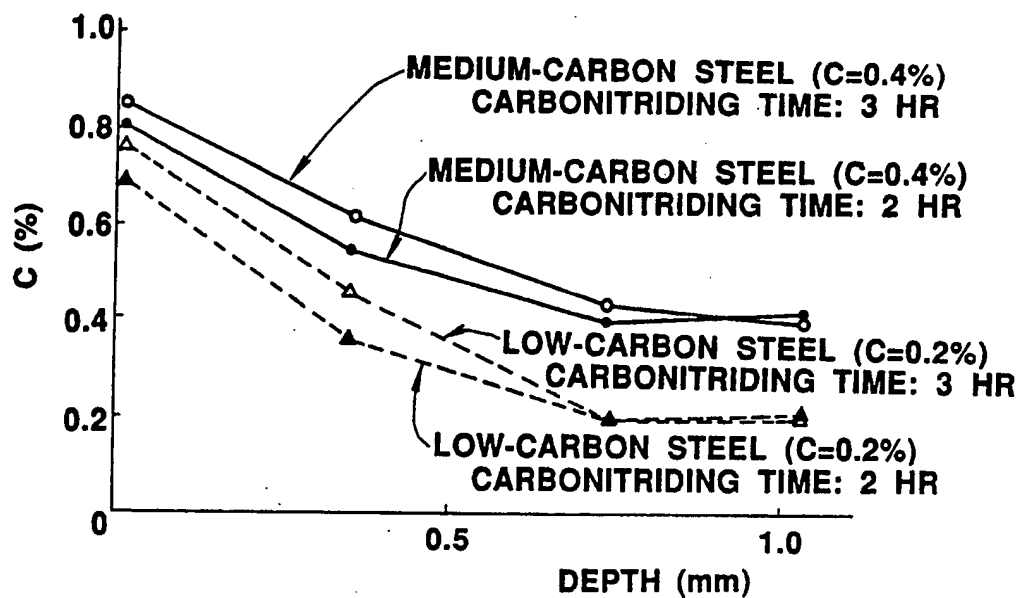
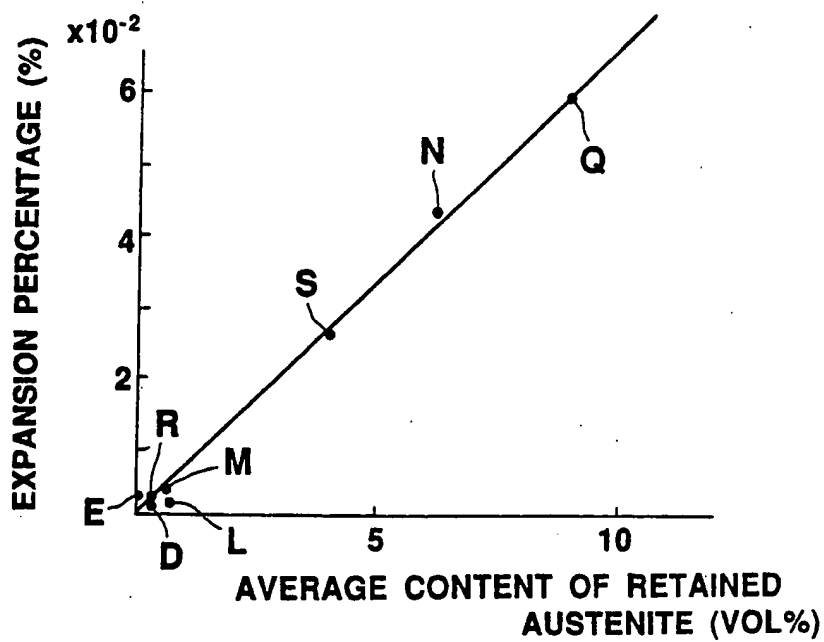


FIG. 4



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FIG. 5

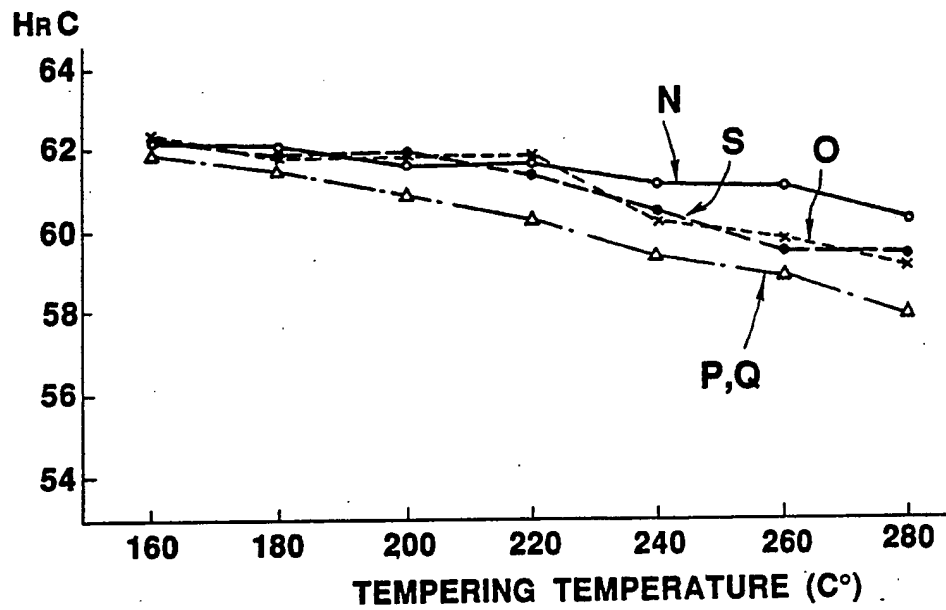
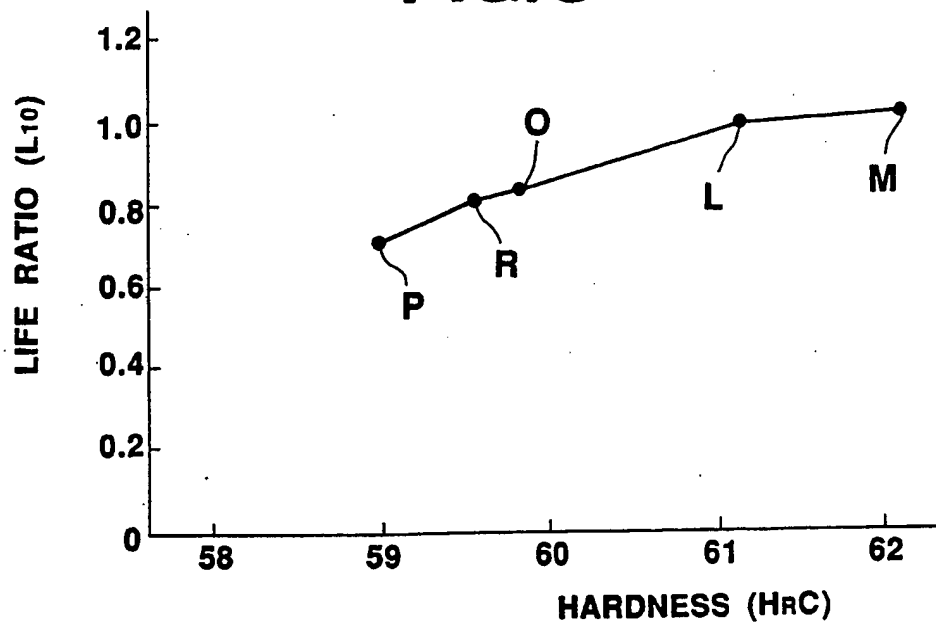


FIG. 6



ROLLING CONTACT PARTS STEEL AND ROLLING BEARING MADE THEREOF

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a rolling contact parts steel for use in bearings used, e.g., with automotive vehicles, agricultural machinery, construction machinery and iron-and-steel machinery and to bearings each including races (an outer race and inner race) and a rolling element at least one of which is made of the rolling contact parts steel and more particularly to a long-lived rolling contact parts steel and long-life rolling bearings required for use in transmission and engine.

2. Description of the Related Art

A rolling bearing is in a severe service under high surface pressure so as to experience a repeated shearing stress. In order to endure the repeated shearing stress and secure rolling fatigue life (hereinafter referred to as life), the rolling bearing with rolling contact part which is made of high-carbon chromium bearing steel (e.g., JIS-SUJ2), then quenched and then tempered so as to have a 30-48 H_RC hardness has been used.

On the other hand, there is a prior-art rolling bearing made of casehardened steel in order to increase its life. This prior-art casehardened steel rolling bearing has been made of a casehardened low-carbon steel of a good hardenability, e.g., JIS-SCR420H, -SCM420H, -SAE8620H or -SAE4320H

since a hardness curve of the casehardened steel rolling bearing must be determined in accordance with an internal shearing stress distribution created by a contact surface pressure. Then, this casehardened steel rolling bearing has been sequentially carburized or carbonitrided, quenched and tempered and thus has secured a required life so that the races and rolling elements of the casehardened steel rolling bearing have a 58-64 H_RC surface or case hardness and a 30-48 H_RC core hardness.

On the other hand, e.g., Unexamined Japanese Patent application publication No. SHO 49-114516 disclosed a prior-art bearing material. This publication provides a carburized medium-carbon steel for rolling contact part including C: 0.36-0.50 wt% and Cr: 0.5-1.5 wt% etc. and teaches that in accordance with this carburized steel use for rolling elements, reducing a carburization time and the content of retained austenite in the carburized surface of the rolling elements increases the tenacity, hardness and fatigue limit of the case hardened rolling elements.

A load on a machine using a rolling bearing has increased and a rotational speed of the machine has increased so that service conditions of the rolling bearing has become severer, and the rolling bearing has been used under a quasi-high temperature to high temperature, which has caused the following problems:

First, an increasing in a service temperature of a rolling bearing decreases the hardness of the rolling bearing, resulting in a plastic deformation in the rolling bearing

thereby to decrease the life of the rolling bearing. Second, using a rolling bearing under high temperature can break an oil film between the races and rolling elements of the rolling bearing, so that a boundary lubrication is ready to occur thereby to accelerate a wearing in the rolling contact parts of the rolling bearing. Third, even when the content of retained austenite present in the carburized surface is reduced, even a slight content of retained austenite present in the surface of a rolling contact part transforms to martensite under quasi-high temperature to high temperature, so that the size of the rolling contact part changes thereby to damage the dimensional stability of the rolling bearing. In particular, a severe dimensional stability of the rolling bearing has been recently required. For example, a slight dimensional error in a rolling bearing used in a jet engine or the like can cause a fatal hazard. Therefore, the rolling bearing in a service under quasi-high temperature to high temperature requires a severe dimensional stability.

Thus, in order to preferentially secure the dimensional stability of the rolling bearing in a service under quasi-high temperature to high temperature, a high-temperature tempered type of high-carbon chromium bearing steel (e.g., JIS-SUJ2) in which the casehardened high-carbon chromium bearing steel has been high-temperature tempered so as to previously transform retained austenite in the rolling contact part of the rolling bearing to martensite thereby to increase the dimensional stability of the rolling contact part has been

conventionally provided.

Precipitation-hardened steel such as M50, high-temperature bearing high-speed steel with Cr, Mo and V, has been provided as a material for quasi-high temperature to high-temperature rolling contact part in addition to the high-temperature tempered type of JIS-SUJ2. M50 is a high-temperature bearing high-speed steel which is high-temperature tempered to precipitate an alloy carbide so as to provide a sufficient high-temperature service strength to a rolling bearing.

In addition, in order to increase the life of a rolling bearing the service temperature of which can be a quasi-high temperature to high temperature, a wear-resistant carburized steel of Unexamined Japanese patent application publication No.SHO 53-37518 or a casehardened steel of Unexamined Japanese patent application publication No.SHO 54-75420 can alternatively used as a material for rolling contact part, for example.

The high-temperature tempered type of JIS-SUJ2 increases the dimensional stability of the rolling contact part while high-temperature tempering decreases the hardness of the rolling contact part and increases a plastic deformation in the rolling contact part made of the high-temperature tempered type of JIS-SUJ2 thereby to decrease the life of a corresponding rolling bearing. In addition, an insufficient wear resistance of the high-temperature tempered type of JIS-SUJ2 can remarkably accelerates a wear in the rolling contact part under a boundary lubrication under a high-temperature serv-

ice of the rolling bearing.

In addition, since the concentration of carbon in M50 precipitation-hardened steel is high and M50 precipitation-hardened steel in the stage of material for rolling contact part has macrocarbides of Cr, Mo and V, the workability in pretreatment of M50 is poor. On the other hand, the macrocarbides cause a stress concentration therearound which can result in a flaking from the place of the stress concentration thereby to decrease the life of a corresponding rolling bearing with rolling contact part made of M50. Thus, M50 must be additionally solution heat treated at a high temperature (about 1,100° C) in order to dissolve the macrocarbides into the matrix of M50 and then particularly heat treated in order to refine the resulting carbides. This requires a separate heat treatment equipment and decreases productivity of heat treatment.

The wear-resistant carburized steel of the Unexamined Japanese patent application publication No.SHO 53-37518 can produce macrocarbides thereby to reduce the life of the rolling bearing. The carburized wear-resistant steel of the Unexamined Japanese patent application publication No.SHO 54-75420 can also produce macrocarbides and in particular, is more likely to do so when the content of carbon is large in the carburized wear-resistant steel.

Conventionally, it has been known that an in-steel nonmetal inclusion, in particular, an oxide-base inclusion deteriorates the mechanical property of a steel. The present inventors confirmed that the prior-art high-carbon chromium

bearing steel, low-carbon alloy steel, casehardened steel etc. failed to take into account a reduction of oxide-base inclusion thereby to reduce the life of the rolling bearing.

Therefore, a primary object of the present invention is to provide a rolling contact parts steel which produce a fine carbide without the need for a separate heat treatment and which will not reduce the hardness even when a rolling contact part made of the rolling contact parts steel is high-temperature tempered in order to increase the dimensional stability of the rolling contact part and which produces a very slight content of an oxide-base inclusion.

Another object of the present invention is to provide a rolling bearing which is made of the inventive rolling contact parts steel and has a long life in a service under not only room temperature but also quasi-high temperature to high temperature.

A further object of the present invention is to provide a rolling bearing which has a good dimensional stability even in a service under high temperature.

SUMMARY OF THE INVENTION

In order to achieve the primary object, a first aspect of the present invention provides a rolling contact parts steel consisting essentially of C: 0.2-0.6 wt%; Si: 0.3-2.0 wt%; Cr: 0.5-2.5 wt%; Mn: 1.7 wt% or less; O: 12 ppm or less; and the balance of Fe and an inevitable impurity.

This rolling contact parts steel may further include Mo: 3.0 wt% or less or V: 0.1-1.0 wt%.

In order to achieve the second-mentioned object, a second aspect of the present invention provides a rolling bearing comprising races and a rolling element, at least one of the races and rolling element being made of the rolling contact parts steel of the first aspect of the present invention. The one of the races and rolling element is carburized or carbonitrided for surface hardening heat treatment, then quenched and then tempered. The one of the races and rolling element is preferably high-temperature tempered at the tempering step. The temperature of the high-temperature tempering is 240-550°C.

In order to achieve the third-mentioned object, a third aspect of the present invention is that the content of retained austenite in the surface layer of the one of the races and rolling element which has been tempered is 3 vol% or less.

One feature of the present invention is that Si and Cr and preferably Mo and V are added to low or medium carbon steel to produce the rolling contact part. Adding Si, Cr, Mo and V increases the tempering softening resistance of the inventive rolling contact parts steel in order to suppress a reduction in the hardness of the rolling contact parts steel caused by tempering even when the rolling contact parts steel is tempered and in particular, high-temperature tempered in order to reduce the content of retained austenite adversely affecting the dimensional stability of the rolling contact part. Thus, the addition of Si, Cr, Mo and V can reduce a high-temperature softening of the rolling contact part.

Since the matrix of the rolling contact parts steel

is made of low or medium carbon steel, the rolling contact parts steel in the stage of material for rolling contact part resists to a production of a macrocarbide. Thus, the rolling contact part steel requires neither complicated solution heat treatment for macrocarbide nor a separate high-temperature treatment equipment, e.g., salt bath.

The sequence of carburizing or carbonitriding, then quenching and then tempering the rolling contact part precipitates fine carbides of Cr, Mo and V in the surface layer of the rolling contact part. The fine carbides present in the surface layer of the rolling contact part increase the wear resistance of the rolling contact part.

The precipitation hardening of the carbides can provide a hardness required under high temperature to the rolling contact part so that the rolling contact part secures a hardness required under quasi-high temperature to high temperature. Thus, the precipitation hardening of the carbides remarkably reduces a plastic deformation in the rolling contact part and avoids a tempering softening of the rolling contact part. The fine carbides reduce a stress concentration in the rolling contact part, so that the rolling contact part of the present invention resist to the occurrences of a flaking and a crack thereby increase the life of a rolling bearing comprising the rolling contact part of the present invention. In addition, fine carbides present in the surface layer of the rolling contact part increases the wear resistance of the rolling contact part. Reducing the content of in-steel oxygen as much

as possible avoids the oxide-base inclusion.

Since the rolling contact part of rolling bearing of the present invention is made of the inventive rolling contact parts steel carburized or carbonitrided, then quenched and then tempered, the rolling contact part has a superior tempering softening resistance, a production of a fine carbide prevents a reduction in the hardness of the rolling contact part even when a rolling bearing comprising the rolling contact part of the present invention is in service under quasi-high temperature to high temperature, the production of the fine carbide also provides a superior wear-resistance to the rolling contact part so that the life of the rolling bearing is increased under a service not only at room temperature but also at quasi-high temperature to high temperature, and a production of the oxide-base inclusion is as much reduced as possible so that the life of the rolling bearing is more increased.

Since the rolling contact part of the rolling bearing of the present invention is even under high temperature, the average content of retained austenite in the surface layer and the core of the rolling contact part is 3 vol % or less. Thus, the dimensional stability of the rolling contact part of the rolling bearing in a service at quasi-high temperature to high temperature is good. Carburizing or carbonitriding the rolling contact part may be selected for surface hardening heat treatment. In particular, carbonitriding is preferable because N, i.e., nitrogen increases the tempering softening resistance of the rolling contact parts steel.

High-temperature tempering a prior-art bearing steel and a prior-art casehardened steel, e.g., at 250°C insufficiently provides a rolling contact part the surface hardness of which is below 60 H_RC so that the surface hardness of the rolling contact part will not meet with the requirement for rolling bearing. On the other hand, carbonitriding the rolling contact part of the rolling contact parts steel of the present invention for surface hardening heat treatment provides a rolling contact part the surface hardness of which will meet with the requirement for rolling bearing because of the tempering softening resistance increasing operation of N even when the rolling contact part is high-temperature tempered. Thus, a sufficient life of the rolling bearing comprising the rolling contact part of the present invention can be secured even when high-temperature tempering the rolling contact part is conducted in order to increase the dimensional stability of the rolling contact part.

Herein, the surface layer of the present invention is defined as a Z_0 to $2Z_0$ deep layer of each of the races and rolling element of the rolling bearing from a rolling contact surface of the rolling contact part when Z_0 represents a position (i.e., depth) of maximum shearing stress. The preferred embodiments of the present invention have, e.g., about 0.2-0.5 mm order thick surface layers. The depth of the surface layer is computed from a value of a surface pressure applied to the rolling contact surface of each of the rolling contact parts, i.e., the races and rolling element.

The present invention can produce fine carbides in the surface layer of the rolling contact parts steel without the need for a separate heat treatment.

The high-temperature tempered rolling contact parts steel of the present invention can provide a long-life rolling bearing in services under both room temperature and high temperature as well as a superior dimensional stability to a rolling bearing in a service under quasi-high temperature to high temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG.1 is a characteristic graph of a rolling thrust bearing in service at 130°C, representing results of a rolling thrust bearing life test in terms of a relationship between the stress repetition cycle number and failure probability of the rolling thrust bearing;

FIG.2 is a characteristic graph of a rolling thrust bearing in service at room-temperature, representing results of a rolling thrust bearing life test in terms of a relationship between the stress repetition cycle number and failure probability of the rolling thrust bearing;

FIG.3 is a characteristic graph of a relationship between a depth from the surface of a tested material and the content of carbon in wt%;

FIG.4 is a characteristic graph of a relationship between an average content of retained austenite and an expansion percentage, representing a dimensional change;

FIG.5 is a characteristic graph of a relationship be-

tween a tempering temperature and the surface hardness of a rolling contact part; and

FIG.6 is a characteristic graph of a relationship between the surface hardness of a rolling contact parts steel and the life of a rolling bearing.

DESCRIPTION OF THE INVENTION

The operations of the included elements of the rolling contact parts steel of the present invention and the critical significance of the contents of the included elements will be described hereinafter.

C: 0.2-0.6 wt%

Carbon was required to increase the hardness of a rolling contact part which had been quenched and then tempered. The captioned values represent the content of carbon present in the core of the rolling contact part since carburizing or carbonitriding a rolling contact part made of the rolling contact parts steel increased a case carbon concentration in the surface layer of the rolling contact part.

Above 0.6 wt% content of carbon caused a macrocarbide in the stage of material of the rolling contact parts steel for the rolling contact part thereby to decrease the tenacity and rupture strength of the rolling contact part. Above 0.6 wt% content of carbon also significantly increased the content of retained austenite thereby to change dimensions of the rolling contact part at high temperature so as to deteriorate the dimensional stability of the rolling contact part.

On the other hand, below 0.2 wt% content of carbon

required a significantly longer time for carburization or carbonitriding thereby to decrease the heat-treatment productivity of the rolling contact part.

For example, increasing a carbonitriding temperature in order to reduce a carbonitriding time increased the decomposition of NH_3 gas, so that nitrogen difficultly entered the rolling contact part. Thus, the carbonitriding temperature was increased only to 820-880°C. Therefore, in order to secure a carbon weight percentage providing a sufficient hardness of the rolling contact part through a depth at which a shearing stress was loaded when the rolling bearing received a load, the carbonitriding time was increased, which is costly.

On the other hand, the content of oxygen producing the oxide-base inclusion harmful to an increasing of the life of the rolling bearing increased as the content of carbon decreased, which is disadvantageous to an increasing of the life of the rolling bearing. The present invention produced a low-oxygen high-clean steel from a medium-carbon steel (i.e., carbon: 0.2-0.6 wt%). Thus, the content of carbon was preferably 0.3-0.6 wt% and more preferably 0.35-0.45 wt%.

Si: 0.3-2.0 wt%

In-steel Si was effective to solution reinforcement and an increasing of the tempering softening resistance of the rolling contact part. The content of Si had to be 0.3 wt% or more in order to exert the operation of Si. However, the greater the content of Si, the lower the mechanical strength and machinability of the rolling contact part. In addition,

Si has carburization and carbonitriding impedances. Thus, the upper limit of the content of Si was 0.2 wt%.

Cr: 0.5-2.5 wt%

Cr was effective to an increasing of the tempering softening resistance of the rolling contact part.

A precipitation hardening producing uniformly distributed fine chromium carbides provided a sufficient surface hardness to the rolling contact part and increased the tenacity of the matrix of the rolling contact part even when the rolling contact part was high-temperature tempered. Hard and fine chromium carbides increased the wear resistance of the rolling contact part. Since Cr is an element producing a chromium carbide so as to increase the content of carbon in a carbonitrided layer of the rolling contact part, Cr increased the carbonitridability of the rolling contact parts steel even when the rolling contact parts steel included a large content of Si impeding carburization.

In order to exert the above operations of Cr and secure a required surface hardness (especially 61-70 $H_R C$) of the rolling contact part, the lower limit of the content of Cr was 0.5 wt%. On the other hand, above 2.5 wt% content of Cr insufficiently produced fine carbides which were uniformly distributed in the rolling contact part and, produced a macrocarbide in the rolling contact part in the stage of material of the rolling contact parts steel for the rolling contact part so as to cause a stress concentration about the macrocarbide thereby to decrease the life of the rolling bearing.

An unnecessarily increased content of Cr is costly. Refining the macrocarbide required a high-temperature quenching of the rolling contact part thereby to reduce the productivity of heat treatment. Thus, the upper limit of the content of Cr was 2.5 wt%. The content of Cr was preferably 1.8-2.5 wt%.

Mo: 3.0 wt% or less

Mo was effective to increasing the tempering softening resistance of the rolling contact part as Cr was, required to produce the carbides in the surface layer of the rolling contact part, and effective to an improvement in the hardenability of the rolling contact part. Therefore, the rolling contact parts steel may include Mo if desired.

However, above 3.0 wt% content of Mo insignificantly increased the above operations and produced a macrocarbide in the rolling contact part in the stage of material for the rolling contact part so that the life of the rolling bearing could be decreased, which is costly. Thus, the upper limit of the content of Mo was 3.0 wt%.

Mn: 1.7 wt% or less

In-steel Mn served as both a deoxidizer and a desulfurizing agent in melting a steel and largely contributed to an improvement in the hardenability of the rolling contact part and Mn is also inexpensive. However, a large content of Mn was likely to produce a large content of a nonmetal inclusion thereby to decrease the life of the rolling bearing, increased the hardness of the rolling contact part and thereby decreased the forgeability and machinability of the rolling

contact parts steel. Thus, the upper limit of the content of Mn was 1.7 wt%. The content of Mn was preferably 0.3-1.6 wt%.

O: 12 ppm or less

Since oxygen produced an oxide or oxide-base nonmetal inclusion (especially Al_2O_3) to decrease the life of the rolling bearing, the content of oxygen was required to be as much decreased as possible. Thus, the upper limit of the content of oxygen was 12 ppm. It was preferably 9 ppm.

Al produced an oxide or oxide-base nonmetal inclusion, e.g., Al_2O_3 , which is harmful to the life of the rolling bearing. However, Al itself served to prevent a coarsening of crystal grains, so that the content of Al may be up to 300 ppm.

V: 0.1-1.0 wt%

V was significantly effective to an improvement in the tempering softening resistance of the rolling contact part and precipitated in grain boundaries thereby to suppress a coarsening of crystal grains and refine the crystal grains, and was bonded with in-steel carbon to produce a fine carbide. Since adding V increased the hardness of the surface layer of the rolling contact part and thereby to increase the wear resistance of the rolling contact part, the rolling contact parts steel may include V if desired. Since a 0.1 wt% or more content of V significantly operated, the lower limit of the content of V was 1.0 wt%. On the other hand, above 1.0 wt% content of V precipitated vanadium carbide in grain boundaries so as to deteriorate the workability and various mechanical properties of the rolling contact part. In addition V is

costly. Thus, the upper limit of the content of V was 1.0 wt%.

In the present invention, the rolling contact parts steel may possibly include other elements as an inevitable impurity in addition to the above elements. Ti, S and P exemplifies the inevitable impurity.

Ti

Ti appeared as a nonmetal compound in the form of TiN. Since the hardness of TiN is high and the plasticity thereof is low, TiN was a source of stress concentration to decrease the life of the rolling bearing. Thus, the content of Ti was as much decreased as possible. The content of Ti was preferably 40 ppm.

P

Since P decreased the impact resistance of the rolling contact parts steel, the content of P was required to be decreased. Thus, the content of P was preferably 200 ppm or less.

S

S caused a sulfide or sulfide-base nonmetal inclusion, e.g., MnS. MnS had a low hardness and high plasticity so as to cause a cracking during a preworking, e.g., rolling and forging, of the rolling contact part. The content of s was required to be as much decreased as possible so that the cracking in the rolling contact part during preworking, e.g., forging was prevented and a harder working of the rolling contact part could be conducted. Thus, the content of S was preferably 80 ppm or less.

In the present invention, the sequence of carburizing or carbonitriding, then quenching and then tempering at least one of the races and rolling element produced fine carbides in the surface layer of the one of the races and rolling element.

These carbides were hard and provided a good wear resistance to the rolling contact part thereby to secure the required hardness of the rolling contact part of the rolling bearing in a service at quasi-high temperature to high temperature and increase the life of the rolling bearing. In addition, these carbides, which are fine, prevented a stress concentration to be caused by a load imposed on the rolling bearing to increase the life of the rolling bearing.

Carbides of the present invention comprise, e.g., Cr_7C_3 , Cr_3C_6 , Mo_2C , VC , V_4C_3 , Fe_3C and double carbides thereof.

Sizes of the carbides of the present invention (defined as $1/2$ of the total of the maximum diameter and minimum diameter of each carbide) are preferably $0.5\text{-}1.0\mu\text{m}$.

The content of the carbides present in the surface layer of the rolling contact part of the present invention preferably are 20-50 vol%.

A desired surface hardness of the one of rolling contact part is 61-70 H_RC in order to increase the life of the rolling bearing. Below 20 vol% content of the carbides failed to provide the desired surface hardness. On the other hand, above 50 vol% content of the carbides inpreferably caused fine carbides to cohere and thereby coarsen so that the cohering carbides caused stress concentration. Thus, the content of the

carbides present in the surface layer of one of the rolling contact parts was 20-50 vol%. This provided the rolling contact part of the surface hardness as high as 61-70 H_RC.

In addition, the carburization and carbonitriding of the blank of the rolling contact part produced the cores of carbides when the rolling contact part was heated above an A₁ transformation temperature and the subsequent quenching and tempering precipitated the fine carbides in the surface layer of the rolling contact part. In addition, providing the 0.6-0.8 wt% content of dissolved carbon and concurrently the 2.5-3.8 wt% total content of carbon present in the surface layer of the rolling contact part provided 20-50 vol% content of the carbides present in the surface layer of the rolling contact part.

In accordance with the present invention, carburizing or carbonitriding the rolling contact parts steel of the compositions defined in the claims provided 0.6-0.8 wt% content of dissolved carbon or carbon-and-nitrogen with a 2.5-3.8 wt% total content of carbon present in the surface layer of the rolling contact part. Quenching and then high-temperature tempering the rolling contact part made of the resulting alloy steel precipitated the fine carbides in the surface layer of the rolling contact part and provided 3 vol% content of retained austenite present in the surface layer and the core thereof. Since because above 3 vol% content of retained austenite transformed to martensite at high temperature thereby to significantly change the dimensions of the rolling contact

part, the average content of retained austenite should be preferably 3 vol% or less.

Since an insufficiently low temperature of tempering the blank of the rolling contact part insufficiently transformed retained austenite to martensite, the temperature of the tempering was about 240-550°C and preferably 250-300°C.

Thus, the present invention can provide the long-lived rolling bearing even when the rolling bearing is in a service at quasi-high temperature to high temperature (i.e., about 120-550°C).

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention will be described hereinafter.

Embodiment 1

Sequentially carburizing or carbonitriding, quenching and tempering the tested materials A and B of the rolling contact parts steels defined in the claims of the present invention and tested materials C to K of control provided the disc-shaped test pieces Nos.1-17 which were applicable to both the races of a rolling thrust bearing. Table 1 shows the compositions of the tested materials A to K.

Table 1

Tested material	C	Si	Mn	Cr	Mo	V	O	S	P
A	0.41	1.21	1.13	2.19	2.14	-	9	60	130
B	0.40	1.20	1.08	2.22	2.06	0.2	9	50	130
C	1.02	0.25	0.36	1.47	-	-	11	40	120
D	0.20	0.25	0.72	1.06	-	-	10	60	130
E	0.41	1.19	1.09	0.68	2.10	-	9	40	120
F	0.42	1.20	1.10	2.13	-	-	10	40	120
G	0.42	1.21	1.10	3.24	3.30	-	9	50	120
H	0.42	1.21	1.10	2.30	2.05	1.1	9	50	130
I	0.42	2.5	1.08	2.8	2.10	-	9	50	130
J	0.41	1.2	2.03	2.9	2.05	-	9	50	130
K	0.41	1.19	1.10	2.20	2.11	0.07	9	50	130

Contents of O, S, and P are represented in ppm and those of the other elements in wt%.

Table 2 shows the conditions of heat treatment for each test piece. The conditions of heat treatment for the test piece No.1 were as follows: A direct quenching of a carburization was conducted under the atmosphere of Rx gas + an enriching gas at 950°C for about 3 hr, then an oil quenching was conducted and then a high-temperature tempering of 300°C x 2 hr was once conducted.

The test pieces Nos.5 and 13 were quenched without carburization and carbonitriding. The other test pieces Nos.2-4, 6-12 and 14-17 were carburized or carbonitrided under varied conditions and tempered at varied temperatures. The test pieces Nos.1-10 and 15-17 were high-temperature tempered in order to reduce the contents of retained austenite. The test pieces Nos.11-14 were tempered at a normal temperature. A carbonitriding instead of carburization was conducted under the atmosphere of Rx gas + an enriching gas + 5 % ammonia.

Then, the surface hardnesses in H_{RC} and the contents of retained austenite of the test pieces Nos.1-17 were measured. Table 2 shows the results of these measurements.

The L_{10} lives of the test pieces Nos.1-17 represented by a stress repetition cycle number were measured. In order to obtain a high-temperature life characteristic of each of the test pieces Nos.1-17, the life of the test piece was measured at a 130°C and at about 50-60°C room temperature. The lives at 130°C of the test pieces Nos. 1-10 and 15-17 and the lives at room temperature of the test pieces Nos.1-14 were measured. A time at which each test piece has experienced a visible flaking

or crack was defined as the expiration of the life of the test piece. The conditions of the life measurement were as follows:

Testing machine: Thrust testing machine described on pages 10-21 of "Special Steels Manual, 1st edition edited by Electrosteelmaking Research Institute and published by Rikohgakusha on May 25, 1965;

Lubricating oil: FKB oil RO 150 in the case of 130°C life test and FKB oil RO 80 in the case of room temperature life test;

Maximum surface pressure: 560 kg/mm² in the case of 130°C life test and 530 kg/mm² in the case of room temperature life test;

Stress repetition cycle number; 3,000 cpm

Table 2 shows the lives of the test pieces Nos.1-17.

Table 2

Test piece No.	Tested material	Conditions of heat treatment		Hardness $H_R C$	Average γ_R (wt%) *1	L ₁₀ life at 130°C (cycle) Values in []: L ₁₀ life at room temperature
		Carburization (Carbonitriding)	Tempering			
1	A	950 °C × 3 hr	300 °C × 2 hr × 1 time	61.2	2-3	1.3×10^7
2	A	(880°C × 3 hr)	300 °C × 2 hr × 1 time	61.3	2-3	1.4×10^7
3	B	950 °C × 3 hr	300 °C × 2 hr × 1 time	61.6	2-3	1.6×10^7
4	B	(880°C × 3 hr)	300 °C × 2 hr × 1 time	61.7	2-3	1.8×10^7
5	C	840 °C × 30min *2	240 °C × 2 hr × 1 time	59.1	0-1	3.1×10^6
6	D	930 °C × 3 hr	240 °C × 2 hr × 1 time	59.4	1-2	5.1×10^6
7	E	950 °C × 3 hr	300 °C × 2 hr × 1 time	60.2	2-3	7.5×10^6
8	F	950 °C × 3 hr	300 °C × 2 hr × 1 time	59.9	2-3	7.4×10^6
9	G	950 °C × 3 hr	300 °C × 2 hr × 1 time	61.1	2-3	1.2×10^7
10	H	950 °C × 3 hr	300 °C × 2 hr × 1 time	61.1	2-3	1.5×10^7
11	A	950 °C × 3 hr	220 °C × 2 hr × 1 time	64.1	4-6	$[1.5 \times 10^8]$
12	B	950 °C × 3 hr	220 °C × 2 hr × 1 time	64.1	4-6	$[1.7 \times 10^8]$
13	C	840 °C × 30min *2	160 °C × 2 hr × 1 time	62.1	8-10	$[9.8 \times 10^6]$
14	D	930 °C × 3 hr	160 °C × 2 hr × 1 time	61.5	4-6	$[4.7 \times 10^7]$
15	I	950 °C × 3 hr	300 °C × 2 hr × 1 time	61.0	2-3	4.0×10^6
16	J	950 °C × 3 hr	300 °C × 2 hr × 1 time	61.4	2-3	6.3×10^6
17	K	950 °C × 3 hr	300 °C × 2 hr × 1 time	61.2	2-3	1.3×10^7

* 1 : Each value represents an average of γ_R s wt% of the surface layer and the core.

* 2 : Quenching was conducted without carburization and carbonitriding.

A relationship at 130°C or room temperature between a stress repetition cycle number and a failure probability of a disc-shaped test piece due to a flaking or crack caused by a repeated stress in the disc-shaped test piece was tested with a plurality of disc-shaped test pieces made with each of the test pieces Nos.1-10. FIG.1 shows the result of this test.

On the other hand, a relationship at room temperature between a stress repetition cycle number and a failure probability of a disc-shaped test piece made of each of the test pieces Nos.11-14 was tested in essentially the same manner as in the case of FIG.1. FIG.2 shows the result of this test. In FIGS.1 and 2, reference numerals indicate corresponding test pieces.

Since the test piece No.1 made of the tested material A precipitated fine carbides in the surface layer thereof and included the elements increasing the tempering softening resistance of test piece No.1 as shown in Table 2, the surface hardness of the test piece No.1 was as high as 61.2 H_RC even when the test piece No.1 was high-temperature tempered. In addition, the high-temperature tempering decreased the content of retained austenite to be as low as 2-3 wt%, so that the dimensional stability in the 130°C life test of the test piece No.1 was good.

Since the surface hardness of the test piece No.1 was thusly good and the carbide present in the surface of the test piece No.1 was fine, the results of the 130°C life test for the test piece No.1 represented good values. Thus, as seen in

FIG.1, the high-temperature failure probability to stress repetition cycle number of the test piece No.1 was low.

The test piece No.2 was made of the tested material A as the test piece No.1. The test piece No.2 differed from the test piece No.1 in that the test piece No.2 was not carburized but carbonitrided.

The H_{RC} hardness of the test piece No.2 was higher than that of the test piece No.1. The content of retained austenite of the test piece No.2 was lower than that of the test piece No.1. The life at 130°C of the test piece No.2 was shorter than that of the test piece No.1. As shown in FIG.1, the 130 °C failure probability to stress repetition cycle number of the test piece No.2 was lower than that of the test piece No.1.

The test piece No.3 was made of the tested material B. The tested material B differed from the tested material A in that the tempering softening resistance of the tested material B was higher than that of the tested material A and included a proper content of V producing and refining a vanadium carbide.

Since the tested material B included the elements increasing the tempering softening resistance as the tested material A and precipitated the fine carbides in the surface layer thereof, the hardness and life of the test piece No.3 were more increased than those of the test pieces Nos.1 and 2 and the 130°C failure probability of the test piece No.3 was low as those of the test pieces Nos.1 and 2. In addition,

since the test piece No.3 was high-temperature tempered, the content of retained austenite of the test piece No.3 was also low as those of the test pieces Nos.1 and 2.

The test piece No.4 was also made of the tested material B. Since the test piece No.4 differed from the test piece No.3 only in that the test piece No.4 was not carburized but carbonitrided, the test piece No.4 had the good results as the test piece No.3.

The test piece No.5 which was made of the tested material C, high-carbon chromium bearing steel of JIS-SUJ2 provided a control. Since high-temperature tempering the tested material C reduced the content of retained austenite, the contents of elements, e.g., Si of the tested material C increasing the tempering softening resistance were low, and the content of carbon of the tested material C exceeded the upper limit of present invention, so that the carbides present in the surface layer of the tested material C were coarsened in the stage of material for rolling contact part thereby to reduce the tenacity and rupture strength of the tested material C. Since the tested material C was neither carburized nor carbonitrided, the degree of the precipitation hardening of the carbides was low so that the hardness of the tested material C required at quasi-high temperature to high temperature failed to be secured. Thus, the 130°C failure probability of the tested material C was much increased as shown in FIG.1.

The test piece No.6 which was made of the tested material D, casehardened steel of SCR420 provided a control.

Since the content of Si of the tested material D increasing the tempering softening resistance was low, the hardness after high-temperature tempering of the tested material C was low and the life thereof was short. As shown in FIG.1, the 130°C failure probability of the tested material D was high.

Since the respective test pieces Nos.7 and 8 were made of the tested materials E and F, the rolling contact parts steel of the present invention, the posttempering hardnesses of the test pieces Nos.7 and 8 were high and the lives at 130°C thereof and the 130°C failure probabilities thereof were lower than those of the test pieces Nos.5 and 6, as shown in FIG.1.

The test piece No.9 was made of the tested material G the contents of Cr and Mo of which exceeded the upper limits of the present invention. Large contents of Cr and Mo can produce macrocarbides thereof. Since the test piece No.9 included the macrocarbides unlike the test piece No.1, the degree of the stress concentration in the test piece No.9 was high thereby to slightly reduce the life of the test piece No.9. On the other hand, adding contents of Cr and Mo exceeding the upper limits of the present invention was inefficient and costly.

The test piece No.10 was made of the tested material H the content of V of which exceeded the upper limit of the present invention. As shown in Table 2, the hardness and life of the test piece No.10 essentially equal those of the test pieces Nos.1-4 and 9 even when the content of V of the test piece No.10 exceeded the upper limit of the present invention. The 130°C failure probability of the test piece No.10 was also

essentially equalled those of the test pieces Nos.1-4 and 9. However, adding an amount of V exceeding the upper limit of the present invention is costly.

The test piece No.11 was made of the tested material A as the test piece No.1 but differed from the test piece No.1 in that the test piece No.11 was not high-temperature tempered but tempered at the normal temperature. Thus, the content of retained austenite of the test piece No.11 was greater than those of the test pieces Nos.1-10. However, since the test piece No.11 included the elements, e.g., Si increasing the tempering softening resistance, the posttempering hardness of the test piece No.11 was good. The life at room temperature of the test piece No.11 was good. As shown in FIG.2, the room-temperature failure probability of the test piece No.11 was good.

The test piece No.12 was made of the tested material B as the test piece No.3 but differed from the test piece No.3 in that the test piece No.12 was not high-temperature tempered but normally tempered. Thus, the hardness and life of the test piece No.12 were good like the test piece No.11. In addition, since the test piece No.12 included V, the posttempering hardness and life of the test piece No.12 exceeded those of the test piece No.11. The room-temperature failure probability of the test piece No.12 was better than that of the test piece No.11.

The test piece No.13 was made of JIS-SUJ2 as the test piece No.5 but differed from the test piece No.5 in that the

test piece No.5 was high-temperature tempered and the test piece No.13 was tempered at the normal temperature.

Since the test piece No.13 insufficiently precipitated fine carbides in the surface layer thereof as the test piece No.5, the hardness and room-temperature life of the test piece No.13 were lower than those of the test pieces Nos.11 and 12. As shown in FIG.2, the room-temperature failure probability of the test piece No.13 was also lower than those of the test pieces Nos.11 and 12.

The test piece No.14 was made of SCR420 casehardened steel as the test piece No.6 but differed from the test piece No.6 in that the test piece No.14 was not high-temperature tempered but tempered at the normal temperature.

Since the content of Si of the test piece No.14 increasing the tempering softening resistance and content of Cr thereof both increasing the tempering softening resistance and causing to produce fine carbides were below the lower limits of the present invention, the hardness and life of the test piece No.14 were lower than those of the test pieces Nos. 11 and 12. As shown in FIG.2, the room-temperature failure probability of the test piece No.14 was higher than those of the test pieces Nos. 11 and 12.

The test piece No.15 was made of the tested material I the content of Si of which exceeded the upper limit of the present invention. The depth of the carburized layer of the test piece No.15 was as much reduced as the content of Si of the test piece No.15 was high, so that the life of the test

piece No.15 was reduced.

The test piece No.16 was made of the tested material J the content of Mn of which exceeded the upper limit of the present invention. The content of a nonmetal inclusion of the test piece No.16 was as much increased as the content of Mn thereof was high, so that the life of the test piece No.16 was reduced.

The test piece No.17 was made of the tested material K the content of V of which was below the lower limit of the present invention. The effect of adding V was insignificant.

Embodiment 1 conducted the life test at 130°C as shown in Table 2. However, a life test at a higher temperature, e.g., about 200-500°C also essentially produced good results as shown in Table 2.

In the life test described with reference to Table 2, the life of each of the disc-shaped test pieces No.1-7 was measured. On the other hand, a life test for test pieces in the form of rolling element made of the same materials as listed in Table 2 was conducted, resulting in essentially the same measurements as in the case of the life test of the disc-shaped test pieces.

Embodiment 2

The tested materials L to S of the compositions of Table 3 were made from ingot steels, then sequentially carburized or carbonitrided, quenched and tempered in accordance with the conditions of Table 4.

Table 3

Tested material	C	Cr	Si	Mn	Mo	O ¹¹	Fe
L	0.41	1.5	0.4	0.6	-	7	balance
M	0.40	1.5	0.4	0.6	1.2	8	ditto
N	0.41	1.5	0.4	0.6	-	7	ditto
O	0.41	1.5	0.4	0.6	-	7	ditto
P	<u>1.0</u>	1.5	0.3	0.3	-	7	ditto
Q	<u>1.0</u>	1.5	0.3	0.3	-	7	ditto
R	0.2	1.1	0.3	0.7	-	12	ditto
S	0.2	1.1	0.3	0.7	-	<u>13</u>	ditto

The values in the columns of carbon, Cr, Si, Mn, Mo and Fe represent the contents of the elements in wt%. The values in the column of oxygen represent the contents of oxygen in ppm (*1). The values in the column of carbon represent the contents of carbon in the stages of previous material for the tested materials. Contents of carbon of the tested materials L to O, R and S which have been carburized were 0.8-1.0 wt%. Those of the tested materials L to O, R and S which have been carbonitrided were 0.7-0.9 wt%.

Table 4

	Heat treatment		Surface hardness (H _R C)	Average content of retained austenite (vol%)
	Surface heat treatment	Tempering (°C)		
L	carbonitriding	260	61.2	0
M	carbonitriding	260	62.1	0
N	carbonitriding	160	62.1	6
O	carburization	260	59.8	0
P	—	260	59.0	0
Q	—	160	61.8	9
R	carburization	260	59.6	0
S	carburization	160	62.0	4

The carbonitriding of Table 4 was conducted under the atmosphere of Rx gas + a 1.5 vol % enriching gas + 3-5 vol % ammonia at 820-850°C for about 3 hr. Then, an oil quenching was conducted from the temperature of the carbonitriding to 60°C and then each of the temperings was once conducted at the temperatures of Table 4 for 2 hr.

On the other hand, the carburization of Table 4 was conducted under the atmosphere of Rx gas + an enriching gas at 930°C for about 3 hr. Then, this temperature was decreased to 830°C. Then, a soaking of 830°C x 30 min was conducted. Then, oil quenching was conducted.

On the other hand, tested materials which were neither carburized nor carbonitrided were soaked in the atmosphere of Rx gas at 830°C and then oil quenched.

The tested materials L and M belong to a rolling contact parts steel of Embodiment 2 of the present invention. The tested material N provided a rolling contact parts steel a tempering temperature of which was low. The tested material O provided a rolling contact parts steel not carbonitrided but carburized. The tested material P provided a control made of high-carbon bearing steel II (i.e., JIS-SUJ2) which was not carbonitrided. The tested material Q provided a control made of the JIS-SUJ2 high-carbon bearing steel a tempering temperature of which was not high. The tested material R which was made of a low-carbon steel not carbonitrided but carburized provided a rolling contact parts steel the content of oxygen of which was 12 ppm. The tested material S which was made of a

carburized low-carbon steel a tempering temperature of which was not high provided a control the content of oxygen of which was 13 ppm exceeding the upper limit of the present invention.

The H_{RC} surface hardness and an average content of retained austenite of each of the tested materials L to S were measured. Since the content of retained austenite of each of the tested materials which have been carbonitrided or carburized has a predetermined gradient through the thickness of the surface layer, i.e., distance between the surface and core of the tested material, an average of the contents of retained austenite of the overall surface layer was employed as the content of retained austenite of each of the tested materials. Table 4 represents the results of measurement of the surface hardness and content of retained austenite.

The average content of retained austenite of the tested material L was 0 vol % due to high-temperature tempering. However, the tested material L secured a sufficient surface hardness (i.e., 60 H_{RC} or more) since the tested material L, which was high-temperature tempered, was carbonitrided.

The tested material M had properties similar to those of the tested material L. In particular, since the tested material M differed from the tested material L in that the tested material M included Mo, the surface hardness of the tested material M was higher than that of the tested material L. Since the tempering temperature of the tested material O equalled that of the tested material L, the content of retained austenite of the tested material O was 0. In addition, the

posttempering surface hardness of the tested material O which had not been carbonitrided but carburized was slightly lower than that of the tested material O which had been carbonitrided.

The tested material P provided JIS-SUJ2. High-temperature tempering the tested material P in order to transform retained austenite of the tested material p into martensite softened the tested material P. Thus, the tested material P which had been high-temperature tempered failed to secure a 60 H_RC or more surface hardness required for increasing the life of rolling bearing.

The tested material Q also provided JIS-SUJ2. Since the tested material Q avoided the softening operation of high-temperature tempering, the surface hardness of the tested material Q was higher than 60 H_RC. However, the retained austenite of the tested material Q remained thereby to deteriorate the dimensional stability of the rolling contact part made of the tested material Q.

The surface hardness of the tested material R which was carburized was slightly lower than that of the tested material R which was carbonitrided.

The life of the tested material S the content of oxygen of which exceeded the upper limit of the present invention was slightly shorter than those of the tested materials L and M the contents of oxygen of which were below 9 ppm.

FIG.3 represents characteristics between carbonitriding times for a medium-carbon steel the content of base carbon

of which is 0.4 wt% and a low-carbon steel the content of base carbon of which is 0.2 wt% and gradients in depth of carbon weight percentage. The carbonitriding atmosphere of the cases of FIG.3 equalled that of Table 4. The carbonitriding temperature of the cases of FIG.3 was 850°C.

As apparent from FIG.3, the carbonitriding time of the medium-carbon steel of the present invention required for producing a carbon weight percentage required for a depth at which a shearing stress is imposed is much shorter than the carbonitriding time of the low-carbon steel. This was advantageous in cost. Thus, the heat treatment productivity of the tested materials R and S made of the low-carbon steel was reduced.

FIG.4 represents the results of test of the dimensional stability at high temperature. In this test, the tested materials L to S were placed in the thermostatic oven at 170°C for 500 hr and then the expansion percentage of 170°C case to room-temperature (20°C) case of each of the tested materials was measured since transforming retained austenite of each of the tested materials L to S into martensite at high temperature expands the tested material.

As apparent from FIG.4, since the contents of retained austenite of the tested materials N, Q and S which were tempered at 160 C, a normal temperature, failed to be 0 vol%, the expansion percentage of each of the tested materials N, Q and S was much high so that the dimensional stability of each of the tested materials N, Q and S should be further improved.

In particular, the content of retained austenite of the tested material Q which was a high-carbon steel and the tempering temperature of which was not high was highest. Thus, the dimensional stabilities of the tested materials L and M of the rolling contact parts steel of Embodiment 2 as well as the control tested materials O, P and R were higher than those of the control tested materials N, Q and S.

FIG.5 represents characteristic relationships between tempering temperatures and the surface hardnesses of rolling contact parts steels. Generally, the higher the tempering temperature, the lower the surface hardness. A reduction in the surface hardness of the tested material N which was carbonitrided was lower by the operation of N increasing the tempering softening resistance than those of the tested materials O and S which were not carbonitrided but carburized. Since the tested material O differed from the tested material only in that the tested material O was not carbonitrided but carburized, it was confirmed that carbonitriding increased the tempering softening resistance. The tested materials P and Q were high-temperature tempered to soften.

Single-row deep-grooved ball bearings (6206) with a 62-mm outer diameter, a 30-mm bore diameter and a 16-mm length was made of the tested materials L, M, O, P and R. A ball bearing life tester produced by Nippon Seiko K.K. measured the L_{10} life of each of these ball bearings.

Conditions of measurement were as follows:

Lubricating oil: FKB oil RO68 produced by NIPPON OIL CO., LTD.;

Bearing load: 1,400 kgf radial load;

Bearing rotational speed: 2,000 rpm;

Test temperature: 150°C.

The life of each of the tested ball bearings was defined as the rotational cycle number at which the tested ball bearings experienced a flaking.

FIG.6 represents a characteristic graph of life ratios of the tested materials L, M, O, P and R when the life of the tested ball bearing made of the tested material L is 1. The higher the surface hardness of the tested material, the longer the life of the tested ball bearing. Since the tempering softening resistances of the tested materials L and M were superior so as to prevent a reduction in surface hardness after high-temperature tempering, the lives of the tested ball bearings made of the tested materials L and M were good. It was confirmed that the below 9 ppm content of oxygen of the tested materials L and M provided good lives of the tested ball bearings made of the tested materials L and M.

In accordance with the above bearing life test, all of the rolling contact parts, i.e., inner and outer races and rolling element, of the tested ball bearing were made of the tested materials L and M of Embodiment 2. However, a tested rolling bearing comprising at least one of the rolling contact parts which was made of the tested material L or M of Embodiment 2 had more increased life than a conventional rolling bearing.

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CLAIMS:

1. A rolling contact parts steel consisting essentially of: C: 0.2-0.6 wt%, Si: 0.3-2.0 wt%, Cr: 0.5-2.5 wt%, Mn: 1.7 wt% or less, O: 12 ppm or less, and the balance of Fe and inevitable impurities.
2. A rolling contact parts steel as claimed in claim 1, further including Mo: 3.0 wt% or less and wherein Si: 0.5-2.0 wt%, Cr: 1.8-2.5 wt% and Mn: 1.6% or less.
3. A rolling contact parts steel as claimed in claim 2, further including V: 0.1-1.0 wt%.
4. A rolling bearing comprising:
races: and
a rolling element, at least one of said races and rolling element being made of a rolling contact parts steel consisting essentially of: C: 0.2-0.6 wt%, Si: 0.3-2.0 wt%, Cr: 0.5-2.5 wt%, Mn: 1.7 wt% or less, O: 12 ppm or less, and the balance of Fe and inevitable impurities, said one of said races and rolling element being carburized or carbonitrided, then quenched and then tempered.
5. A rolling bearing as claimed in claim 4, wherein the

rolling contact parts steel further includes Mo: 3.0 wt% or less and wherein Si: 0.5-2.0 wt%, Cr: 1.8-2.5 wt% and Mn: 1.6 wt% or less.

6. A rolling bearing as claimed in claim 5, wherein the rolling contact parts steel further includes V: 0.1-1.0 wt%.

7. A rolling bearing as claimed in claim 4, wherein said one of said races and rolling element is high-temperature tempered at the tempering step.

8. A rolling bearing as claimed in claim 4, wherein C: 0.3-0.6 wt%, Si: 0.3-1.5 wt%, and Mn: 0.3-1.7 wt% and wherein the one of said races and rolling element is carburized at the carburization and carbonitriding step and high-temperature tempered at the tempering step.

9. A rolling bearing as claimed in claim 8, wherein the rolling contact parts steel further consists essentially of Mn: 3.0 wt% or less.

10. A rolling bearing as claimed in claim 5 or 6, wherein said one of said races and rolling element is high-temperature tempered at the tempering step and wherein an average content of retained austenite of said one of said races and rolling element is 3 vol% or less.

11. A rolling bearing as recited in claim 7, 8, 9, 10 or 11, wherein the temperature of the high-temperature tempering step is 240-550°C.